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FIRST RESULTS OF THE METEOROLOGICAL OFFICE EXPERIMENTS ON THE ARTIFICIAL STIMULATION OF RAINFALL

By B. C. V. ODDIE, B.Sc.

Summary.—The results of 19 experiments on the artificial stimulation of rainfall are examined. They indicate rather strongly that a net decrease of rainfall has been produced, but it is argued that this result is too improbable on physical grounds to be accepted. It is inferred, however, that the standard rainmaking technique, when applied to frontal clouds in level country, is most unlikely to yield an appreciable increase—a conclusion which agrees with the findings of the United States Advisory Committee on Weather Control.

When, in September 1955, the Meteorological Office started its experiments on the artificial stimulation of rainfall, it was estimated that about three years' observations would be required before any useful conclusions could be drawn. This period has now elapsed, and it seems desirable therefore to take stock, but it must be said at the outset that satisfactory experiments have been far fewer than was expected, so that this is merely an interim report.

The experimental procedure was fully described in *Weather*.[1] Briefly it consists of releasing a "smoke" formed of minute crystals of silver iodide, from five generators set out on Salisbury Plain in a line, 23 miles long, at right-angles to the prevailing west-south-westerly wind. The generators are brought into operation when rain is expected: the crystals are carried upwards by turbulent diffusion, and there is reason to expect that, if some of them can reach a height at which the temperature is $-6°C.$ or lower, they may assist in the formation of ice crystals and so, perhaps, stimulate the formation of precipitation by the Bergeron–Findeisen process. The method is, essentially, the standard rainmaking method which has been used commercially, especially in the United States of America, for about a decade, and the main object of the trials was to obtain some estimate of its effectiveness in this country.

Since one experiments only in wet weather, the result one has to seek is a local increase due to seeding, over and above the natural level of rainfall. If the natural rainfall were uniform over the region considered, this would be a simple matter. Unfortunately the natural spatial variations of rainfall are quite large enough to conceal any increase which we can reasonably hope to produce by seeding. This difficulty can be overcome by combining the results of a sufficiently large number of separate experiments in a manner to be explained in the next paragraph; but the number of experiments needed is likely to be intolerably large unless the trials are limited to cases in which *random* spatial

variations are as small as possible. For this reason experiments were carried out only on occasions with a broad south-westerly airstream covering all England south of the Humber and with layered frontal cloud giving a fall of five millimetres or more of rain in the Salisbury area.

The examination of results is carried out graphically. We first pick out all the occasions suitable for seeding according to the definition just given, in some convenient period—actually the 10 years 1946–1955. These are called the "historical occasions" and there are 150 of them. Next, we list all the most reliable rainfall stations in the experimental region—all England east of a line from Bournemouth to Liverpool and south of latitude 53½°N. When this list has been trimmed a little to give a reasonably uniform distribution we are left with about 160 stations; and for each of these, we extract the average value, $\bar{r}$, of the rainfall on the historical occasions. In the analysis of results, the rainfall at each station is invariably expressed as a fraction, R, of $\bar{r}$; this has a number of

FIGURE 1—RAINFALL ON 27 SEPTEMBER 1956 EXPRESSED AS A PERCENTAGE OF NORMAL

The broken line represents SP.

advantages, of which the most obvious is that it eliminates systematic spatial variations such as the tendency of rainfall to be heaviest over hills or on windward coasts. If there were such a thing as an average occasion, R would be one at every station.

For each experiment we draw a map showing by means of isopleths the distribution of R over the whole experimental region. Figure 1 is an example. We also draw on this map a line SP through the source S in the direction of the mean wind from the ground up to the $-10°C$. level. Since the silver iodide is likely to take effect, if at all, at about this level, we should expect the centre of the seeded area to be somewhere on this line. Having prepared such maps for all available occasions we, in effect, superpose them in such a manner that all the points S and the wind directions SP coincide, and then prepare a composite chart showing the distribution of mean R in relation to the line SP. Obviously, success in seeding would be indicated by a region of high mean values of R centred somewhere on SP.

The actual results of the 19 satisfactory seeding experiments completed by the end of 1958 are shown in Figure 2. The line SP is drawn up the page. The large figures show mean values of R over a square of side 16 miles (a quite arbitrary distance determined by the scale of the charts used) and the distribution of R is made clearer by isopleths. The mean value of R over the whole figure is 110 per cent. This departure of 10 per cent from the expected value is not large enough to have any statistical significance. The startling fact about Figure 2 is that,

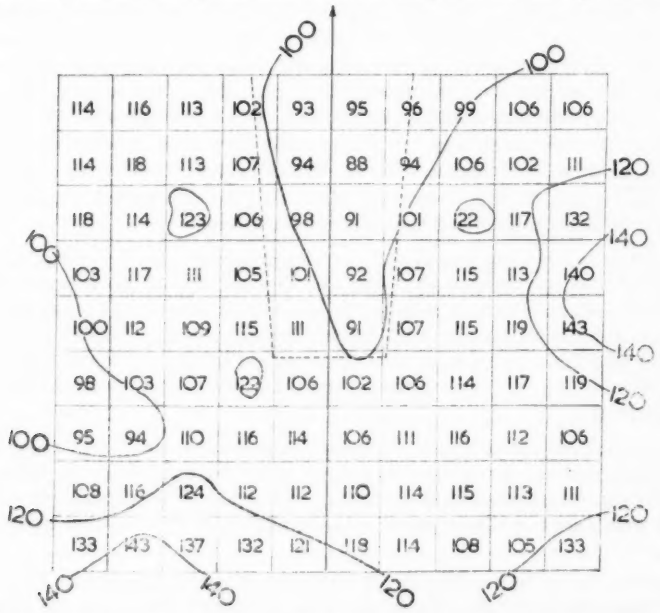

FIGURE 2—MEAN RAINFALL MAP FOR 19 SEEDING OCCASIONS FROM OCTOBER 1955 TO DECEMBER 1958

The broken line represents the expected area of seeding.

almost precisely where one expects the results of seeding, there is the only large area of *low* values of R in the figure! This area actually contains the five lowest entries of the 90 plotted.

The design of this experiment was based on an analysis by R. F. Jones[2] which reached the conclusions:

(1) "The effect of seeding from a single generator is likely to be confined, if the mean wind is constant in direction, to a narrow sector probably subtending less than 10° at the generator."

(2) "In the absence of upcurrents the maximum effect is likely to be detected . . . at a distance of 65–120 miles in average winter conditions and 120–180 miles in average summer conditions."

If one takes these two statements at their face value, the expected area of seeding is indicated in Figure 2 by the dashed line. It is, evidently, an astonishingly close fit to the area of low rainfall. Must we then conclude that seeding has reduced rainfall? In other words, is the reduction indicated by Figure 2 significant in the statistical sense? Unfortunately this is a difficult question to answer. The problem was considered by Jenkinson[3] but his solution, though sound in principle, has not proved easy to apply in practice. The following is a somewhat oversimplified outline of the theory.

Consider two unseeded and roughly equal areas A and B, and let R, on a given occasion, have the values R_A and R_B in these areas. Jenkinson showed that the values of $(R_A - R_B)$ are, very nearly, normally distributed about the mean, which is of course zero. We will call D the standard deviation of $(R_A - R_B)$ as derived from the historical occasions—that is, in the absence of seeding. Now suppose we perform n seeding experiments and arrange that A is in all cases the seeded area and B an unseeded one; we can test the effectiveness of seeding in the usual way, by comparing the mean value, $\overline{(R_A - R_B)}$, obtained in these experiments with D. We can regard seeding as effective if $\overline{(R_A - R_B)}$ is greater than about $2{\cdot}6$ times $D/\sqrt{n}$ since the odds against this occurring by chance are more than ninety-nine to one.

When the experiment was planned it was proposed that the unseeded area used in this comparison should be the sum of a number of areas surrounding the seeded area as closely as possible. In this way it was thought that D could be reduced to about 40 per cent. It was hoped that three years' operations would yield at least 60 trials, so that $D/\sqrt{n}$ would be about five per cent and a mean value of $(R_A - R_B)$ of thirteen per cent would be significant at the one per cent level.

This would be a simple rule to apply if the seeded and comparison areas were rigidly defined. Unfortunately this is not so; we are left free to adjust the area, shape, and orientation of the comparison areas as we please. There is no way in which we can divest ourselves completely of this unwanted freedom of action.

However, let us be as objective as possible. It was suggested by R. P. W. Lewis (unpublished), *before* the results were examined, that since the shape of the seeded area was likely to be a narrow strip lying along the mean wind direction, the most suitable comparison areas were the two strips of the same total area lying on either side of, and as close as possible to, the seeded strip.

We take, therefore, as the seeded area columns 5 and 6, rows 5–9 of Figure 2 and as the comparison area columns 3 and 8, rows 5–9. Columns 4 and 7 are omitted because they are on the border between seeded and unseeded areas. The mean value of R in the seeded region is 95·4 per cent; the mean value in the comparison area is 112·4 per cent—a difference of 17 per cent. The odds against this being a chance result are estimated as at least fifteen to one.

It must be admitted that this estimate is not a very reliable one because of uncertainty about the appropriate value of D. However, we can obtain a very similar result by examining the individual experiments to see how often seeding appears to have produced an increase and how often a decrease. For this purpose, the seeded and the two comparison areas were drawn out on each of the individual charts (similar to Figure 1). The mean rainfall in each area was estimated without reference to the contours, by simply averaging the values of R for the stations lying within the area. Table I summarizes the results.

TABLE I—NUMBER OF CASES IN WHICH $(R_A - R_B)$ HAS VALUES SPECIFIED

$(R_A - R_B)$ 100	−60 to −40	−40 to −20	−20 to 0	0 to 20	20 to 40	40 to 60	60 to 80	80 to 100	100 to 120
Number of cases	1	1	3	6	6	0	0	1	1

The mean value of $(R_A - R_B)$ so obtained is 17 per cent, in good agreement with that obtained from Figure 2. It will be seen that in 14 out of 19 cases, seeding appears to have produced a decrease—that is, $(R_A - R_B)$ is negative. The odds against so high a proportion being of the same sign are fifteen to one.

This examination of the individual cases showed that, in fact, a very good case could be made out for excluding the only two large positive values of $(R_A - R_B)$. The largest of all (49 per cent) was for an occasion when the wind was due south; it was therefore not an "occasion suitable for seeding" by our definition. The next largest positive value (25 per cent) was for the only occasion on which there was a large backing of wind during seeding; in consequence both the comparison areas lay within the seeded region. A careful examination has not revealed any valid objection to any other cases, so that these two are clear exceptions. If one excluded them, one would be left with 14 apparent decreases of rainfall against only three increases. The odds against so high a proportion of the same sign are seventy-seven to one. However, such adjustments of data *a posteriori* are very dangerous and one should perhaps not draw any conclusions from them.

Thus the statistical evidence for an artificially-induced decrease of rainfall is strong but by no means conclusive. It is, however, supported by some facts which our relatively crude statistical method is unable to take into account, but to which some weight ought to be attached. Thus, the area of low rainfall is not merely in the expected place—it is of the expected shape and has the expected orientation. On the other side we have the fact that the result, if it is real, is very hard to explain. It is true that there are innumerable references in the literature to the possibility of overseeding—that is, converting so high a proportion of the water droplets of the cloud into ice crystals as to prevent or reduce the formation of precipitation by the Bergeron–Findeisen process (which depends on the growth of an ice crystal by evaporation from much more numerous water droplets surrounding it). However, a litre of cloud usually

contains some hundreds of thousands of cloud droplets, so that overseeding is likely to require a concentration of hundreds or perhaps thousands of nuclei per litre. It can easily be shown that our installations cannot yield concentrations approaching these figures. For we know that each of our generators yields about 5×10^{14} nuclei per hour. Taking a wind speed of 20 kilometres per hour as representative, we can use one of Sutton's well known equations[4] to calculate roughly the maximum concentration of nuclei at a height of three kilometres, which is the sort of height at which they take effect. The concentration turns out to be less than two per litre. It is hard to believe that this can constitute "overseeding".

The actual concentrations produced may well be even lower, for the equation just used is valid only in conditions of neutral thermal equilibrium. In the conditions of the experiment, there is usually a slightly stable lapse rate, so that the rate of upward diffusion of the silver iodide is probably less than that calculated. A few experiments have been carried out to test this point, in cloudy weather with lapse rates similar to those which were found on the seeding occasions. The material released was not silver iodide, but a fluorescent powder which is easy to detect by optical methods, and its vertical distribution at a point 50 miles downwind from the source was measured by sampling units carried at several different heights on the cable of a captive balloon. According to the equation already cited[4] the concentration at 4,000 feet should have been about 75 per cent of that at the surface; in fact, it varied between one and five per cent.

It is true that, because the fluorescent powder cannot be used satisfactorily in rain, the diffusion experiments were carried out in conditions different from those of the seeding trials, and possibly less favourable to upward motion; but they give us some reason to doubt whether significant numbers of silver-iodide nuclei can reach the level at which they take effect, before they pass out of our experimental region. On physical grounds, then, it seems unlikely that our experiments can have affected rainfall appreciably. Very probably, therefore, the apparent decrease shown in Figure 2 is merely the result of a remarkable coincidence.

The one conclusion of which we can be reasonably sure, since both statistical and physical arguments lead to it, is that we have not produced any appreciable *increase* of rainfall. It does not of course follow that all cloud-seeding is useless; it is even conceivable that the same procedure, applied in other meteorological conditions, might be effective. But it seems almost certain that seeding on this scale (which is about the same as that employed in commercial rainmaking) is ineffective when used on frontal cloud in level country. This conclusion is in agreement with the findings of the United States Advisory Committee on Weather Control[5] which states: "In non-mountainous areas . . . statistical procedures did not detect any increase in precipitation which could be attributed to cloud seeding". The same report adds, however: "No evidence was found in the evaluation of any project which was intended to increase precipitation that cloud-seeding had produced a detectable negative effect on precipitation."

It seems therefore that, if the decrease we appear to have produced is real, it is a unique result.

Acknowledgments.—The analysis of data and its reduction to the form of Figure 2 was carried out successively by Messrs. A. F. Jenkinson, R. P. Waldo Lewis and J. R. Probert-Jones, to whom my thanks are due.

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THE FREQUENCY AND INTENSITY OF SHOWERS IN SOUTHERN ENGLAND IN RELATION TO UPPER AIR SOUNDINGS

Some studies have been made at the Napier Shaw Laboratory, Dunstable, of the relation between the frequency and intensity of showers in southern England and the vertical stability and other parameters assessed from a representative upper air sounding. A preliminary study was carried out by Mr. D. Jones of the Nigerian Meteorological Service during a short stay at Dunstable, and a further investigation was made by Mr. P. M. Hamilton, who worked at Dunstable for a few weeks under the scheme by which university students spend part of their vacation at a Government scientific establishment. The following note is based primarily on Mr. Hamilton's results.

This second investigation was concerned with an area of about 75,000 square miles in central southern England on certain days between January 1950 and April 1953. The days were restricted to those on which cloud and any precipitation were almost entirely due to heat convection from the surface; that is, they were not conditioned by large-scale dynamical factors. Occasions with marked wind shear in the vertical were rejected.

Observation registers from about fifteen stations were examined and on each of the days an assessment was made of the shower activity within the region over the period 1200 to 1800 G.M.T. Occasions with a marked geographical bias in shower distribution were not considered further. Showers on the other days were termed "isolated" if there was an average of up to one per station, "scattered" if between one and two per station and "widespread" if more than two. The classification of intensity (slight, moderate, heavy) was that of the heaviest shower in the area. Association with thunder was noted and also the occasions of "no showers". The vertical distribution of temperature and humidity was taken to be represented by the Larkhill 1400 G.M.T. sounding. Thus no element of forecasting was present.

The accompanying Figure 1 gives the most significant of the results. In it the occurrence, distribution and intensity of showers are displayed in relation to the "condensation-level temperature" and the "depth of convection". Condensation-level temperature was determined from the tephigram in the conventional manner, using the highest maximum dry-bulb temperature in the region and a representative surface dew-point. Depth of convection was the

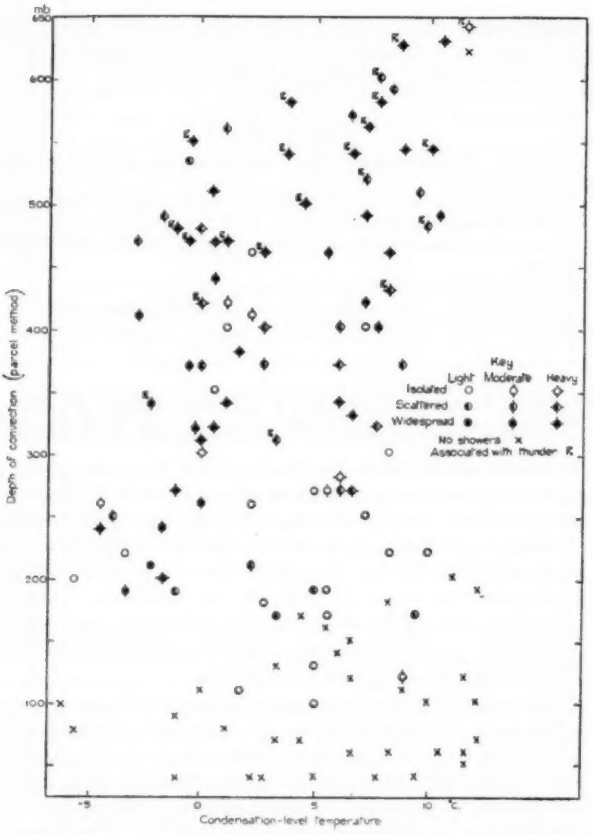

FIGURE 1—RELATION OF DISTRIBUTION AND INTENSITY OF SHOWERS TO DEPTH OF CONVECTION AND CONDENSATION-LEVEL TEMPERATURE

pressure difference between this condensation level and the level where a parcel lifted adiabatically from the condensation level would first attain the same temperature as the environment.

Figure 1 gives some illustration of the difficulty which besets the forecaster in these situations. There is some evidence of grouping of occasions of similar character, mainly according to depth of convection; this grouping being most evident in the distinction between "shower" and "no shower" cases, and between thunder and no thunder. Broadly it shows that showers rarely occur if the depth of convection is less than 5,000 feet and that thunder is probable when it exceeds 15,000 feet; results which accord with forecasting experience.

The "no shower" case in the top right-hand corner of the figure deserves mention. On this very warm day (18 May 1952) pressure distribution over England was almost uniform and there was little difference between the Larkhill and Liverpool soundings. Temperatures rose most rapidly in a belt

from Lancashire across the west and south Midlands to the London area. Surface humidity was highest in the first two areas and thunderstorms developed widely there by early afternoon. The London area was not affected until evening. It may well have been that such an organized outbreak of thunderstorms inhibited shower development elsewhere.

Other possible measures of shower activity which were examined by Mr. Hamilton included the level at which the lapse rate becomes less than the saturated adiabatic as used by Petterssen *et alii*,[1] available energy released by a convective element, Fawbush indices,[2] mean humidity at 500, 600 and 700 millibars and partial thicknesses 1000–700 millibars and 700–500 millibars. None showed more promise as a forecasting tool than the depth of convection as used in the figure.

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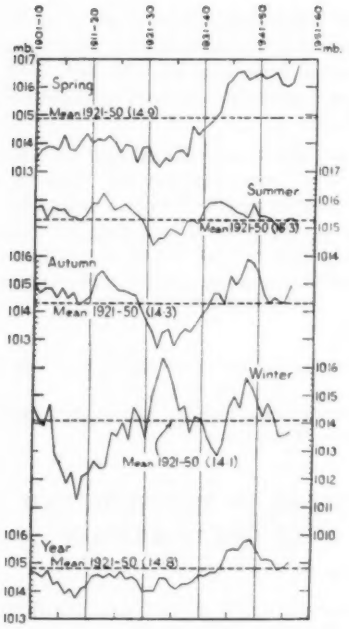
RECENT SEASONAL CLIMATIC TRENDS OF PRESSURE AND TEMPERATURE VARIABILITY OVER GREAT BRITAIN

By J. GLASSPOOLE, Ph.D.

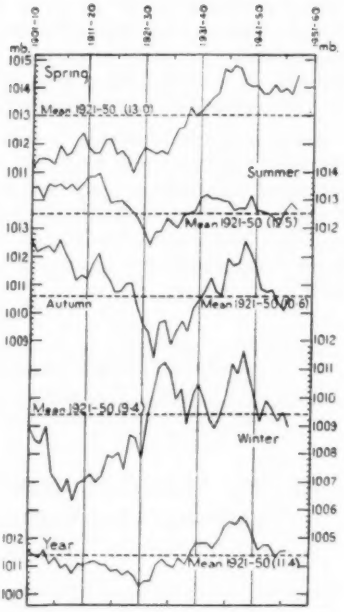
An earlier note[1] on new climatological averages for Great Britain and Northern Ireland, published in the *Meteorological Magazine*, explained how general monthly values of temperature, sunshine and rainfall were obtained. These were used to give a comparison of the new averages with those previously used in official publications. In the case of pressure the comparison was made direct from maps for the old and new periods without reference to the serial monthly values. A further note[2] dealt with the seasonal climatic trends based on the serial values of temperature, sunshine and rainfall, and a third note[4] with the seasonal trends in the number of rain-days. This fourth note considers the trends of pressure in a similar manner and the trend in the 20-year standard deviation of temperature.

Atmospheric pressure, corrected to mean sea level.—Serial monthly pressure values for England and Wales, and for Scotland, for the period 1901 to date were prepared from the maps published in the *Monthly Weather Report*. The mean for each month was taken for 10 fixed points evenly distributed over England and Wales and 10 points over Scotland. The values were corrected where necessary to 0900 G.M.T. and converted from inches to millibars to give a series of 0900 G.M.T. values in millibars.

The two curves of the 10-year moving averages for England and Wales, and for Scotland (Figure 1) show slight differences, but on the whole the trends are similar. The outstanding feature of the annual pressure curves is the general increase in the decadal values in the latter part of the period. The increase for England and Wales was from 1013·7 to 1015·9 millibars from 1909–18 to 1941–50 and for Scotland from 1010·3 to 1012·8 millibars from 1921–30 to 1939–48. The general trend shown on the two curves is similar; it is noticeably similar to that of temperature but is inversely related to that of rainfall.



(*a*) England and Wales



(*b*) Scotland

FIGURE 1—CURVES OF 10-YEAR MOVING AVERAGES OF MEAN-SEA-LEVEL PRESSURE (IN MILLIBARS) FOR GREAT BRITAIN AT 0900 G.M.T.

The main features of the curves for England and Wales are:—

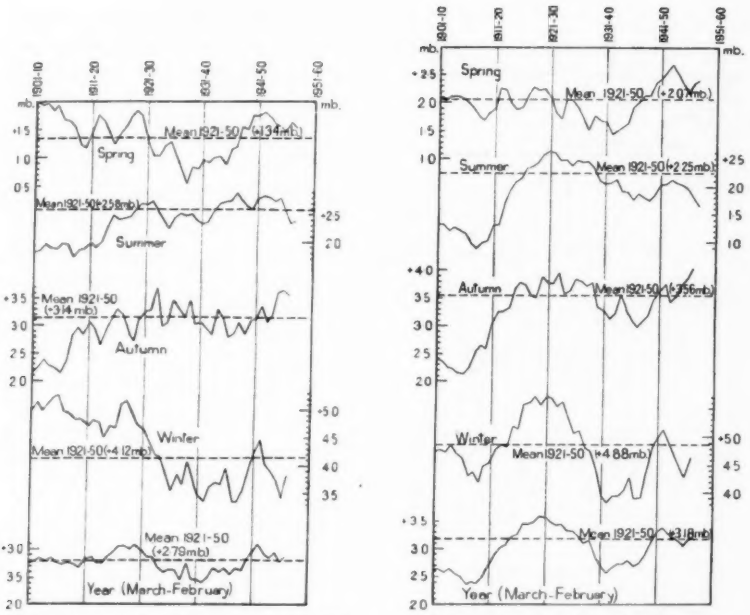
Spring.—A steady increase from a minimum in 1923–32 of 1013·2 millibars to a maximum in 1948–57 of 1016·8 millibars. The similarity with the temperature trend is very striking.

Summer.—An increase from a minimum in 1922–31 of 1014·4 millibars to a maximum in 1934–43 of 1015·9 millibars.

Autumn.—An increase from a minimum in 1923–32 of 1012·6 millibars to a maximum in 1939–48 of 1015·9 millibars, followed by a marked decrease of pressure.

Winter.—The recent winter trend is quite different from that shown by the spring, summer and autumn curves, there being maxima of 1016·4 and 1015·6 millibars in 1924–33 and 1939–48 and a minimum of 1012·8 millibars in 1934–43. Here again, there is a marked inverse relationship with the winter rainfall curve and some similarity with the winter sunshine curve.[2]

Pressure gradients.—Values for the pressure gradients were prepared by reading off the monthly and annual maps the differences in the pressure (*a*) Dungeness–Carlisle, (*b*) Carlisle–Stornoway, and (*c*) Valentia–South Shields, corresponding to pressure gradients from south to north (or more precisely south-east to north-north-west) over England and Scotland and from west to east (or more precisely west-south-west to east-north-east) across the British



(*a*) England and Wales—Dungeness to Carlisle (*b*) Scotland—Carlisle to Stornoway

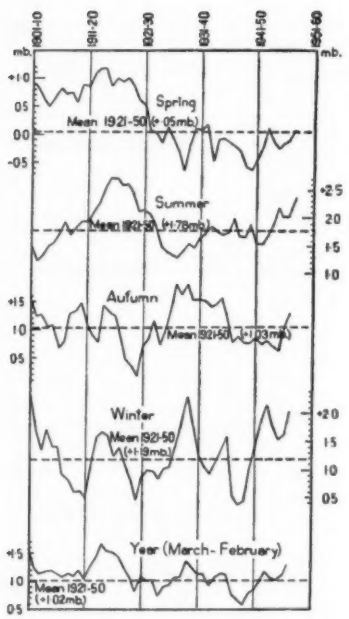
FIGURE 2—CURVES OF 10-YEAR MOVING AVERAGES OF PRESSURE GRADIENTS (IN MILLIBARS) FROM SOUTH TO NORTH OVER GREAT BRITAIN

Isles. The values were corrected where necessary to 0900 G.M.T. and converted from inches to millibars to give a series of 0900 G.M.T. values in millibars.

The curves of the 10-year moving averages of the pressure gradients from south to north over England and Scotland are shown in Figure 2 and those for the British Isles from west to east in Figure 3.

The curves of the south-to-north gradients for England and Wales and for Scotland have some general resemblance, but many marked differences. There is general accord in the values for the year, with maxima in 1920–29 and 1942–51 and a minimum in 1932–41. The curves suggest variations in the zonal circulation, there being less interchange of air between high and low latitudes during the two peak periods, when with the increased frequency of westerly winds heavier rainfall, especially in the west, would be expected. It is interesting to note that when the pressure and temperature commenced to increase about 1921–30 the pressure gradient decreased, but later increased again. The rainfall generally decreased during this period but the decrease might well have been greater but for this increase in the pressure gradient.

The general trend of the south-to-north gradients for England and Wales is similar in the winter and spring, and also in the summer and autumn, but the trends of these two pairs of curves are markedly different. The values for the winter and spring decreased to a minimum and then increased of recent years, while the summer and autumn started with low values which have steadily increased.



British Isles—Valentia to South Shields

FIGURE 3—CURVES OF 10-YEAR MOVING AVERAGES OF PRESSURE GRADIENTS (IN MILLIBARS) FROM WEST TO EAST OVER THE BRITISH ISLES

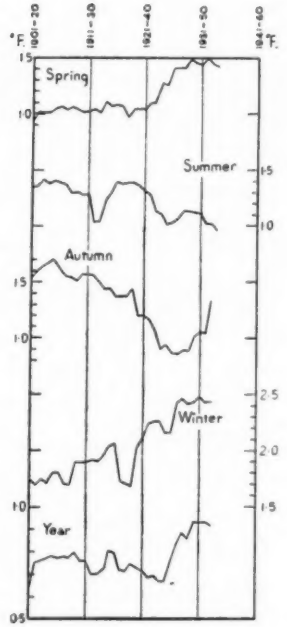


FIGURE 4—CURVES OF 20-YEAR STANDARD DEVIATIONS OF TEMPERATURE (IN °F.) FOR ENGLAND AND WALES

The general trend of the west-to-east gradient could be regarded as indicating changes in the deflexions from the normal trend of the isobars, or of the interchange of air between high and low latitudes. The curve for the spring indicates a change from increased northerly to increased southerly winds, fitting in with the temperature pattern of the trend, but clearly the complicated changes cannot all be explained in such simple terms.

Temperature variation.—Another factor which needs to be taken into account in considering trends is the change in the variability. Figure 4 shows the running 20-year standard deviations of temperature for England and Wales. The curves of the 20-year running means of temperature both for England and Wales and for Scotland are much smoother than those for 10-year means. They bring out the rise of temperature in the spring, summer, and autumn and the year commencing with the period 1912–31. The curves of standard deviation show wide fluctuations as years with extreme values are included within the 20 years, but there are definite trends. The following comments apply to the curves for England and Wales:—

Spring.—As the temperature increased so the standard deviation increased.

Summer.—As the temperature increased so the standard deviation decreased, or the temperature became more uniform.

Autumn.—As the temperature increased so the standard deviation decreased and the two curves show a marked inverse relationship.

Winter.—A marked inverse relationship of recent years when the winter temperatures were very variable.

Year.—Of recent years the standard deviation has increased corresponding with the general increase of temperature.

Relationship between pressure and rainfall.—It was shown[3] that the correlation coefficient of general pressure over the British Isles for each year 1868 to 1921 with the general rainfall was equal to −0·83. The corresponding values for the years 1901 to 1954 now under consideration are set out below:–

	Correlation coefficient
England and Wales	−0·81
Scotland	−0·60

Comparing the curves for England and Wales of running 10-year means of pressure with those of rainfall, the following points call for comment:—

Spring.—There is a marked inverse relationship, but this broke down towards the end of the period. With the increase of pressure from 1923–32 to 1936–45 the rainfall steadily decreased, but although the pressure increase continued, and large values persisted, the rainfall also showed a steady increase.

Summer.—Again there is a marked general inverse relationship.

Autumn.—While the inverse relationship is well marked, the second peak in the pressure curve is higher than the first peak, although the second rainfall minimum is not as low as the earlier one. Thus recent rainfall amounts have not been as small as might have been anticipated from the pressure trend.

Winter and year.—The inverse relationship in the trends is well marked in both cases, although the rainfall curve has not given so low a minimum recently as might be expected from the pressure curve.

The correlation coefficients of the running 10-year means of pressure and rainfall for the 40 values from 1902–11 to 1941–50 are set out below, summarizing the information given above for England and Wales:—

	Spring	*Summer*	*Autumn*	*Winter*	*Seasonal year*
England and Wales ...	−0·70	−0·63	−0·82	−0·85	−0·85

The correlation coefficients depend on the summation of the effects of the passage of depressions across the country and are related to the running 10-year means and not directly to the annual values. Examination of the curves indicates that the relationship is closer at some times than others, and this accounts for the relatively small values for the spring and summer over England and Wales.

Relationship between pressure and temperature.—In view of the marked relationship between the trends of pressure and temperature in the spring, the correlation coefficients were calculated for the 40 values 1902–11 to 1949–50 for each season and the year for England and Wales:—

	Spring	*Summer*	*Autumn*	*Winter*	*Seasonal year*
England and Wales ...	+0·94	+0·33	−0·03	−0·18	+0·58

It is clear from the curves that if the correlation had been restricted to the period of the marked temperature increase, that is, from 1922–31 to 1943–52, then there would have been a marked positive correlation during the spring summer, autumn and year.

Summary.—The object of these articles has been to give a broad picture of recent climatic trends over Great Britain for further study. It is clear that there are a number of inter-related factors. The most outstanding trend is undoubtedly the increase of temperature from about 1922–31 to 1943–52.

The general inference is that the Azores high pressure system has tended to move further north since 1922–31, as shown by the pressure trends for the spring, summer and autumn. The temperature increased while the rainfall decreased. Initially in this period the pressure gradient from north to south decreased but later there was an increase and but for this the rainfall might well have decreased further. The rainfall has also been maintained by the increase since1922–31 in the mean rain per rain-day, especially in the spring.[4]

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THE FARNBOROUGH WEATHER FLIGHT

By M. P. GARROD

For the past three years a routine weather reconnaissance flight has been made by the Ministry of Supply from the Royal Aircraft Establishment (R.A.E.), Farnborough, and the data obtained forwarded to the Central Forecasting Office, Dunstable. These flights have been carried out by Royal Air Force crews and Meteorological Office observers, and it may be of interest, particularly to forecasting staff, to know how this service came into being and how it is carried out.

In February 1955 the Experimental Flying Department at Farnborough decided that, in addition to the normal meteorological services, a routine flight would assist in the planning of each day's flying, and would help to reduce the risk of flights being wasted. Discussions between the Experimental Flying Department, the Meteorological Office and the Meteorological Research Flight (M.R.F.) at Farnborough resulted in the decision that a flight would take place each weekday, that aircraft and aircrew would be provided on a rota system by the various sections in R.A.E., and a trained observer from M.R.F. would be carried on each flight provided that it did not interfere with current M.R.F. work. The data to be collected would consist of visual observations of cloud and weather as directed by the Meteorological Office and the Officer Commanding Experimental Flying.

The first flight took place on 3 March 1955, and subsequently 780 flights have been made during the period to December 1957. During the first few months the accent was not so much on the weather for the day at Farnborough as on that expected at various places where R.A.E. aircraft were planning to fly, such as bombing and firing ranges. However, by 1956 the flights were extended, when necessary, so as to satisfy the requirements of the Meteorological Office, Farnborough, as well as R.A.E. As a result of this change the information forwarded to the Central Forecasting Office at Dunstable contained much more significant information.

The pilot, navigator and observer for the flight report to the Meteorological Office at 0730 hours to discuss the weather with the duty forecaster and decide on a flight plan. The route chosen by the forecaster is either towards a frontal system, which is expected to affect southern England during the subsequent 24 hours, or in a general upwind direction. The forecaster may also suggest where an ascent or descent through cloud layers would be of use, but the final flight pattern is left to the pilot, since it is dependent on the weather, airways, control zones etc.

The aircraft normally used for these flights is the Canberra, but when none of these is available a Meteor VII is substituted. The latter has a rather limited duration and is not so suitable for these particular flights. By 0750 hours the crew are aboard, the observer occupying an ejection seat beside the navigator and behind the pilot. Take-off time is 0800 hours but some variation from this is inevitable from day to day. The observer's seat next to the navigator provides a very restricted view outside the aircraft, but a folding seat beside the pilot commands a very good view ahead and to the starboard side. When safety height is reached and the pilot is satisfied that everything is functioning normally, the observer moves forward to this seat. He remains there until the aircraft is within two or three minutes flying time of Farnborough.

A typical routine is to climb to the top of the highest cloud and then make a level run, with minor horizontal or vertical divergences, to the furthest point detailed, which may be anything up to 300 miles from Farnborough. Provided that time and fuel allow, descent might then be carried out to check all the cloud layers, and the return to base made at a low altitude. Considerable deviation is possible from the original flight plan if more significant weather is observed off track, and weather checks are frequently made over the Ministry of Supply's airfield at Thurleigh, Bedford, if requested by radio during the flight.

The observer's task is to try to obtain an accurate log of the weather over a period up to 1½ hours. This, owing to the complex structure of clouds, with rapid changes over short periods of time (aircraft speed 500 miles per hour) is frequently difficult to accomplish. Too detailed information is not easy for the forecaster to assimilate and takes too long to transmit by teleprinter. As a result the observer has to record a very general picture of the cloud seen and to include information on cloud bases, tops and amounts of the major layers only.

Of the many problems which arise in observation of clouds from aircraft, not the least is the classification of clouds. For example, cirrus is quite often found below 20,000 feet during winter months and has been seen below 15,000 feet. An eight-eighths layer of cloud very similar to stratocumulus has been observed

with a base at 22,000 feet and top at 25,000 feet. Any meteorological observer will appreciate the difficulty of cloud classification in these cases. One can easily be deceived when flying at high altitudes by the appearance of clouds, partly because of the lack of a scale of distance. On one occasion a belt of cirrostratus was seen which resembled the early stages of a front. Barely two minutes after entering the cloud the aircraft flew out of the other side into a clear sky!

Apart from making observations at intervals during the flight, the observer can sometimes relax and appreciate the scenery, both in the air and on the ground. One flight is rarely similar to another and, if there is little weather to be seen, a short period of aerobatics may add some excitement to a dull sortie.

After each flight the observer returns to the Meteorological Office, briefly gives the general details to the forecaster and records the significant features in a special book. This account, on completion, is forwarded by telephone to the Air Traffic Control Centre, Uxbridge, and is subsequently broadcast by teleprinter from the Central Forecasting Office, Dunstable, to outstations. To illustrate the form of these reports, as broadcast, the details of the weather observed on 20 March, 1957 are shown below. The synoptic chart for 0900 G.M.T., with flight track, is shown in Figure 1, and a rough cross-section of the cloud reported in Figure 2.

URUK FARNBOROUGH 0815–0945Z. QNH 995 MB.

FARNBOROUGH 0815Z. 8/8 NS BASE 500 FT TOP 15000 FT EMBEDDED CU TOPS 16000 FT NO CLOUD ABOVE. MOD TURBULENCE UP TO 7000 FT.

FARNBOROUGH–ST. DAVID'S HEAD 0825–0855Z. BROKEN UPPER CLOUD W OF WINCHESTER, NIL W OF SALISBURY. 4/8 CU OR SC. LARGE CU BRISTOL AREA TOPS 10000–15000 FT, LOCALLY 6/8. OVER S WALES 2/8–5/8 CU TOPS 6000–8000 FT. ISOLATED CB TOPS 15000 FT W OF PEMBREY CB TOPS EXCEEDING 20000 FT ISOLATED TOPS 29000 FT. CB WELL SCATTERED OVER BRISTOL CHANNEL.

ST. DAVID'S HEAD–CHERBOURG 0855–0920Z. SCATTERED CB TOPS 20000 FT OVER EXMOOR. SMALL CU, FEW LARGE CU EXETER REGION. SLT TURBULENCE AT 28000 FT AND 23000–24000 FT OVER COAST. 2/8–3/8 CU OVER CHANNEL. LIGHT TO MOD. TURBULENCE BELOW 9000 FT CHERBOURG. EDGE OF UPPER FRONTAL CLOUD BETWEEN 8000 AND 10000 FT AT CHERBOURG BEC 8/8 TO SE. 2/8 CU BASE 2100 FT TOPS 3500 FT.

CHERBOURG–FARNBOROUGH 0920–0940Z. 2/8–3/8 SC OVER CHANNEL. SLT TURBULENCE 8000–11000 FT. EDGE OF ACAS SHEET OVER SHOREHAM WITH 8/8 MIXED SC AND CU REACHING 10000 FT. 2/8 SMALL CU AT TANGMERE NO UPPER CLOUD. 2/8–3/8 CU BASE 2000 FT AT FARNBOROUGH. MOD. TURBULENCE BELOW 2000 FT.

NINE MINUTES OF CLOUD DECAY

By G. W. REYNOLDS

This nine-minute series of five photographs (Plates I–V between p. 144 and p. 145) of the same cloud demonstrates how rapidly a good sized cumulus cloud can dissipate. The shots were centred around 1715 C.S.T. one afternoon in June 1954 at College Station, Texas. They were all taken from the same location with a slowly changing horizon. The cloud base at the time of the first shot was an estimated 2000 feet.

[*To face p. 144*

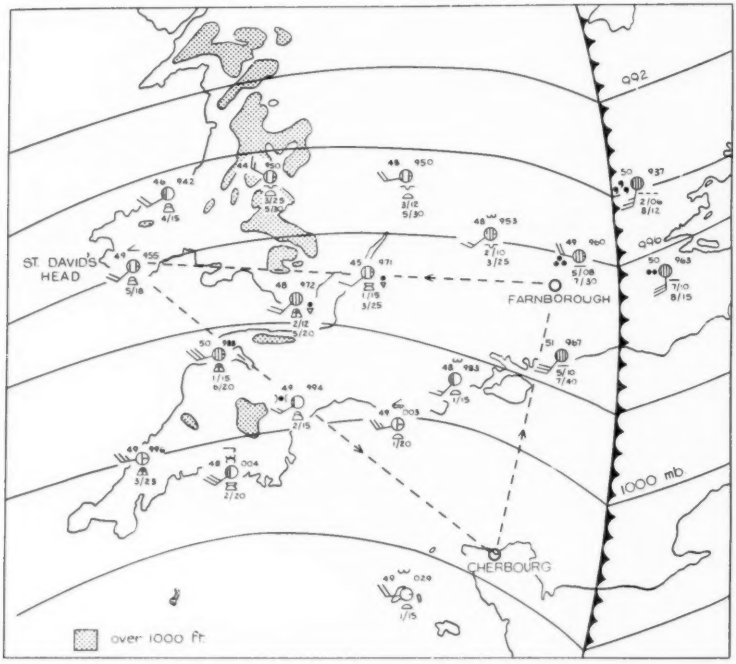


FIGURE 1—SYNOPTIC CHART FOR 0900 G.M.T., 20 MARCH 1957

The broken line is the flight track of the weather reconnaissance aircraft from Farnborough 0815–0945 G.M.T.

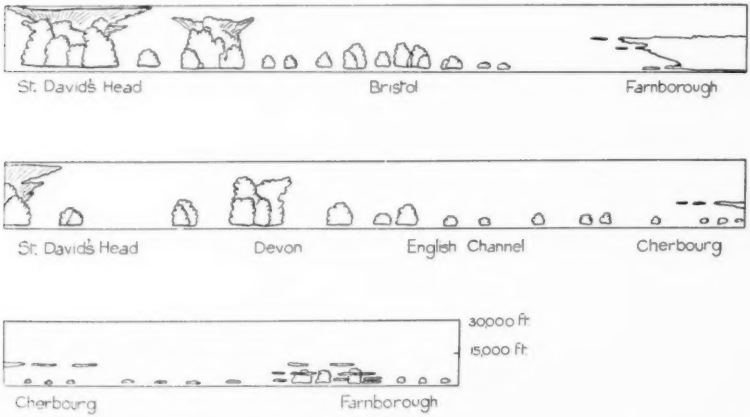
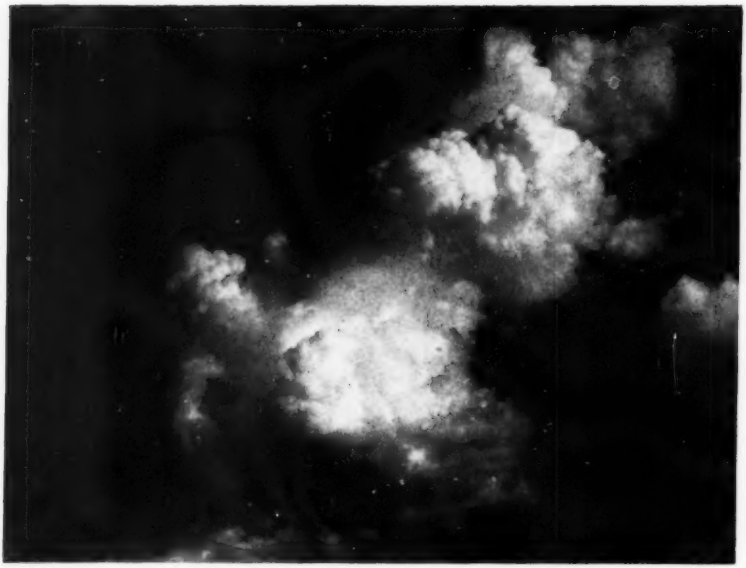


FIGURE 2—CROSS-SECTION OF CLOUD REPORTED BY RECONNAISSANCE FLIGHT, 20 MARCH 1957



Photograph by G. W. Reynolds

PLATE I

Photograph by G. W. Reynolds

PLATE II

NINE MINUTES OF CLOUD DECAY

(see p. 144)

Photograph by G. W. Reynolds

PLATE III

Photograph by G. W. Reynolds

PLATE IV

NINE MINUTES OF CLOUD DECAY

(see p. 144)

To face p. 145]

Photograph by G. W. Reynolds

PLATE V

NINE MINUTES OF CLOUD DECAY

(see p. 144)

The pictures were taken with a $2\frac{1}{4} \times 2\frac{1}{4}$ twin-lens reflex camera. Plus-X film was used with a lens opening of f16, a shutter speed of 1/50 and an orange filter. It was a fairly high contrast sky.

The rate of decay illustrated here is not at all unusual in this area. As a matter of fact, cloud dissipation may occur as swiftly in many parts of the world. Note how the top leans over as the dissipation progresses. This is not an illusion resulting from the translation of the cloud. Notice also how the decay progresses more rapidly near the bottom of the cloud.

Acknowledgments.—The author is indebted to Mr. James Sullivan and Mr. Lowell P. Riggs of the Department of Oceanography, Texas Agricultural and Mechanical College, for their useful suggestions concerning the techniques of cloud photography.

METEOROLOGICAL OFFICE DISCUSSION
Meteorological measurements at airfields

The discussion held on Monday, 19 January 1959, at the Royal Society of Arts was opened by Mr. C. H. Hinkel.

General considerations.—Meteorological measurements at airfields could be divided broadly into two classes; those made by an observer visually with a minimum of instrumental aid and those necessarily made by means of instruments. The first class contained general weather characteristics, visibility, cloud type, amount and height and the second class wind, pressure, temperature and humidity measurements. This classification was by no means rigid or complete, but the intention was to consider only those parameters which played a part in the aviation side. All other measurements not of direct use to aviation had been deliberately excluded.

The first class of measurements were essentially subjective. The difficulty of obtaining agreement between individual observers was increased by ill-defined cloud base, haze, mist and precipitation or when nocturnal measurements were required. It was therefore unfortunate that these quantities controlled the pilot's ability to land or take off from a given airfield. Weather and cloud were necessarily visual determinations and could not easily be replaced instrumentally. The work which had been done in this field by the use of radar techniques was as yet largely exploratory.

In order to measure visibility the observer noted the furthest object which could be seen and identified out of a series of selected objects at known distances. The determination was necessarily directional but the observer could often note variation round his horizon, and so overcome this limitation. At night-time the visibility was expressed in terms of the equivalent day-time visibility and lights at known distances replaced objects. The distance at which a light could be seen depended upon its brightness, the sensitivity of the observer's eye, the presence (or absence) of other lights in the field of vision, the level of illumination and the atmospheric transparency. The last named was the quantity to be measured in order to retain consistency with daylight observations. The sensitivity of the eye varied from observer to observer as well as individually with time and, red light excluded, was greater for indirect than for direct vision. Furthermore the indirect vision sensitivity increased for about an hour after going into darkness, but adaption for direct vision in darkness took

about two minutes. The pilot, however, really required a slant visibility which could be very different from the horizontally measured values.

Lack of background made visual cloud height estimation difficult and a uniform sheet of cloud or a diffuse base increased the difficulties. Some assistance might be obtained from local topographical features and aircraft in the circuit could be used either as a guide or to provide information, but were not always reliable.

Instrumental measurements, although objective, gave only spot values and meteorological measurements were normally required in the form of mean values representative of a large area or of a period of time. Thus measurements at one spot of a parameter, subject to rapid fluctuations of moderate amplitude in both space and time, would not necessarily give a good representation of the mean conditions over the airfield. Under these conditions an instrument with a fast response and great sensitivity was of limited value. By reducing the sensitivity and response a better approximation to the time mean could be obtained. The introduction of conventions in order to compare measurements at one place with those at another could introduce errors greater than those of the instruments themselves. The exposure of the instruments was thus important if representative space means were required. The alternative was a large number of instruments forming a close network over the area concerned. They would have to be read simultaneously and a mean value extracted. The cost of the instruments for such a network might be small but the cost of installing them would, in most cases, be prohibitive.

Visibility.—Instrumental measurements of visibility depended upon a determination of either the attenuation of a beam of light from a source of known candle-power, or the intensity of the back-scatter or diffuse reflection of a beam of known power. The measurement was limited to the light path and did not give a representative picture of the surrounding air. The difficulty could be partly overcome by causing the instrument to scan a large number of lights arranged uniformly around the horizon. Similarly back-scatter instruments could be made to scan round the horizon. The fundamental disadvantage of this type of measurement was the inability of the instrument to detect discontinuities in the transparency of the air.

Cloud height.—Cloud-base measurements presented a similar type of problem, for the difficulties were mainly due to the non-uniformity of the parameter and the limited field of vision of the instrument. The international definition of cloud base was vague and gave trouble when there was a diffuse cloud base. It was under these conditions that instrumental readings were sometimes open to doubt.

Pilot-balloon measurements were affected by a number of factors, for they depended upon the observer noting when the balloon started to disappear into cloud, upon an assumed rate of ascent which could be upset by eddies or precipitation, or upon the balloon entering the base and not the side of the cloud.

At night the measurements were usually made by means of a searchlight which projected a narrow beam of light vertically upwards to produce a spot of light on the cloud, and the angle which this spot subtended at the end of a known base line was measured. The spot produced was about 35 feet in

diameter at 1,000 feet and the light penetrated some distance into the cloud so that the observer saw not a circle but a diffuse cone of light whose vertical extent depended upon the nature of the cloud and was largest when the cloud was diffuse. The accuracy of measurements under these conditions was about 150–200 feet. The logical development of this method was to replace the human eye by photo-electric detection of the light spot; and by pulsing or chopping the light beam at a known frequency to produce an interrupted beam, detection would be possible under daylight conditions. Searchlights working on this principle were in use both in Europe, the United States and, experimentally, in this country. An alternative method used the light after the manner of a radar set and measured the time taken for light pulses to reach the cloud and be reflected back again to the ground. Molecular back-scatter made separation of transmitter and receiver necessary if cloud heights below about 1,000 feet were required. Synchronizing the electrical and light pulses introduced some inaccuracies, and it was important to realize that the instrument measured a time interval which was converted into a height, just as the previous system measured an angle. Both methods could be used by day as well as by night and the first system could easily be made distant-recording.

Wind.—Wind observations were complicated by vertical variations and a height of ten metres was taken as the standard height for measurement. Gustiness and eddies caused by buildings or other obstructions provided a further complication, and readings were usually taken as means over a period of time; even so, truly representative values of the surrounding terrain were difficult to obtain.

Three types of instrument were commonly used. The rotation type of anemometer was probably the most familiar, and consisted of three or four hollow hemispherical cups mounted symmetrically about a vertical axis with the diametral plane of each cup vertical. In gusty winds the intrument tended to read high and the inertia of the cup system damped out the effects of gustiness, so that the instrument measured a mean wind. It was thus particularly useful for airfield work.

The Dines pressure-tube anemometer was the familiar example of the second type of instrument, which measured the difference between the static and the dynamic or total air pressures caused by the airflow. The system had good accuracy and response provided that the gust frequency was not greater than about one per second. Direction was obtained from the vane usually by means of a rod coupling to the building below. Friction and inertia in the coupling introduced some loss of response.

The third class of anemometer depended upon the heat exchange between a current-carrying wire and the airflow past it. They were very sensitive but fragile and required shielding for outside use. Anemometers of this kind were not normally used at airfields.

Pressure.—Measurements of pressure would be discussed only in relation to the hypsometer. This instrument worked on the principle that a pure liquid boils when its saturation vapour pressure equalled the applied pressure. Thus measurement of the boiling point of pure water enabled the saturation vapour pressure to be determined and hence the atmospheric pressure. The instrument was simple, easy to operate and transport, but required measurement of

temperature to 0·01°C. in order to measure pressure to within one millibar. Thermometers of this accuracy were expensive and the measurements took quite a time to make.

Temperature and humidity.—Temperature and humidity measurements were treated together since the humidity was usually obtained indirectly from two temperature measurements. In common with wind and pressure measurements, the exposure of thermometers was important if representative results were to be obtained, as the air was by no means homogeneous and considerable fluctuations occurred both in space and time. Thermometers were normally exposed in a well-ventilated screen so that they were shaded from direct radiation or precipitation. Because of variations in temperature with height it was conventional to arrange the screen so that the thermometers were four feet from the ground, but this convention was not universally adopted on the Continent. A more difficult condition to satisfy was that the screen walls should be at the temperature of the ambient air. All thermometers were subject to lag errors whose magnitude depended upon the rate of change of temperature and upon the type of thermometer in use. Very generally the lag was greatest for liquid-type thermometers and least for the electrical types.

Humidity measurements were made by means of wet- and dry-bulb thermometers, and the wet-bulb readings were therefore subject to the same errors as the dry bulb. The wet-bulb lag was less than that of the dry bulb thus giving rise to an error in the humidity. Further errors were caused by bad ventilation, dirty muslin and a poor water feed to the wet bulb in conditions of low relative humidity and at wet-bulb temperatures below freezing point. Other methods of humidity measurement utilized the hygroscopic properties of lithium chloride or phosphorus pentoxide, and had the advantage that they could be calibrated to read a dew-point direct. They were, as yet, laboratory instruments and would require considerable development before introduction for general use.

Rainfall and sunshine.—Rainfall and sunshine were measured at most airfields and although their applications were almost entirely climatological a brief mention of them would be made. Rainfall was universally measured by catching the fall in a funnel of known dimensions, and carefully measuring the quantity of water thus collected. The instrument's exposure was vitally important as losses were almost entirely due to wind eddies disturbing the catch and it was probable that the gauge itself by projecting above the ground interfered with the catch. Sunshine recorders were basically of two types: those which utilized the heating power of the sun's radiation and those which used chemical action produced by the visible and ultra-violet radiation. With a few exceptions all the instruments were sundials and once set up required little attention. Individual measurements differed considerably but the total sunshine over a period showed only small variations from one instrument to another.

Future developments.—Finally, we ought to give some thought to the future. The observer had already been replaced by instrumental observation in principle at least. The next stage was to make the entire system of observation automatic, but a system of that type brought with it a requirement for special equipment to handle the mass of data obtained. The use of submarine buoys by the Germans in the last war pointed the way to automatic weather stations, and the recent advances in telemetering could be utilized to enable measurements

made automatically at isolated places to be telemetered to a central collecting unit. From the meteorologists' point of view reliability was extremely important as long-period continuous operation under all climatic conditions was necessary for the success of any such venture. At the moment most equipment of that type was both costly and unreliable, so that the problem of reliability was the next hurdle to be jumped before automatic measurements became part of normal routine.

Opening the general discussion the *Director-General* said that care must be taken to distinguish between accuracy and sensitivity; an instrument could be accurate but insensitive. He had read that hypsometers were in regular use in the United States and were regarded more favourably than aneroids.

Mr. Hamilton described experiments carried out at Prestwick to determine whether aneroids could be used in place of mercury barometers. Pressure measurements were required as an altimeter setting and in a synoptic report. In the former case the readings were rounded to the nearest millibar and only amended when in error by one millibar, and an error of 0·5 millibar was thus tolerable. For synoptic reports readings were given to 0·1 millibar and an idea could be formed of the errors which occurred by plotting a synoptic chart containing about half the stations, drawing in the isobars and then estimating the pressure at the stations not plotted. This had been done on two occasions: (*a*) in a quiet anticyclonic situation, when the standard error was 0·4 millibar, and (*b*) in a strong gradient when the standard error was 0·65 millibar. The effects of topography could be very marked and it had been shown that a 15-knot acceleration of air past an obstacle produced a pressure anomaly of 1·1 millibars. At Prestwick two barometers in separate rooms gave readings differing by 0·5 to 1 millibar when the wind speed exceeded 25 knots. From this it seemed not unreasonable to use a slightly less accurate instrument if its other qualities compensated for the loss of precision. Further experiments had shown that the random errors of measurement of pressure by precision aneroid gave a standard error only slightly larger than the mercury barometer. In addition they were easily transported, and capable of being read more rapidly.

Dr. Robinson pointed out that the hypsometer referred to by the Director-General was designed for radio-sonde use above 100 millibars. The Germans, during the war, had made good use of the hypsometer for surveying purposes by using it as a local standard and thus obtained consistent readings, whereas our own system using mercurial barometers had proved to be inconsistent.

Mr. Cornford pointed out that the discussion of both aneroid and hypsometer methods had overlooked the reduction to mean sea level.

Mr. Hinkel agreed that the hypsometer only gave the station-level pressure and that further errors arose when corrections to mean sea level were made particularly at high-altitude stations.

Mr. D. Forsdyke outlined the current development of the hypsometer method as used in the Meteorological Office, and emphasized that the main difficulty lay in obtaining thermometers of sufficient accuracy.

Dr. Best considered that, in making observations of visibility instrumentally, a perfect instrument giving values which differed from those made by a human observer would be regarded as being wrong.

Dr. Stewart said that visibility was defined in terms of the average observer, and whereas individuals vary, instruments as a whole did not.

The Director-General said that visibility presented a partly psychological problem. For example, a stationary man could be invisible against his background but became visible immediately he moved. We could in fact measure "contrast" and "transmission" but not "visibility".

Dr. Stewart considered that the international definition of visibility did not depend upon individual psychology.

The Director-General said that much of the trouble arose from the shortness of the light path used in attenuation instruments.

Mr. D. D. Clarke said that attenuation measurements by instruments could only be related to visibility distances when the scattering was of Rayleigh type, and so were not applicable to measurements made in fog. He thought the Germans had now changed over to aneroids and were using optical levers to overcome the usual friction troubles of the movement.

Mr. Hinkel pointed out that the Instruments Division were carrying out tests with an aneroid which sensed the movement of the capsule electrically and should thus be free from friction troubles.

Dr. Frith said that the World Meteorological Organization had given up the idea of visibility distance and used meteorological visual range, that is, the distance in which intensity was reduced to one fiftieth of its initial value. This gave rise to the difficulty of observing it and translating the observations into a form of practical use to the pilot.

Dr. Murgatroyd thought that the airlines were interested in a slant visibility and a runway visual range in terms of lights visible on touch down, but not in meteorological visibility.

Mr. Harrower emphasized the airlines' requirement for runway visual range, but said that it was not suitable for exchange between aerodromes, nor was slant visual range a solution to the problem unless equipment could be set up near the runway. The importance of the runway visual range lay in the fact that it was the only factor which determined whether an aircraft could take off or land.

Mr. Bibby said that Dr. Frith's transmission definition was really the same as the old definition in terms of a black object against a light background, and the equivalent of a two per cent contrast.

Dr. Robinson noted that the United States Air Weather Service had planned for automatic visibility observations at all airfields in the United States by 1963. This would include transmissometers, cloud height and general background illumination recorded instrumentally and fed into a computer.

Mr. Harrower said that the system was developed by the United States Weather Bureau and gave the approach line control height and runway visual range. The system assumed a homogeneous atmosphere and a homogeneous light pattern from the runway lights. We knew that both these factors were not uniform.

Mr. Wallington said that the system had a strong statistical basis and did not work well if there was a marked variation of visibility with height.

Dr. Robinson wondered if human observers produced better results as they must always assume a statistically homogeneous atmosphere.

Mr. Maidens said that the main interest of the experiment lay in the computing aspect. In the United Kingdom we had to get both the transmissometer and cloud height meters accepted before anything could be done. On account of the high cost of these experiments he thought that only a prototype would be ready by 1963.

Dr. Best considered that the human observer took heterogeneity into account whenever possible, for example, fog banks in the distance were reported, if visible.

Mr. Maidens suggested that, as the observer may be hampered by obstructions round his horizon, it might be better to measure transmission instead of visibility.

Mr. Garnett said that visibility was a difficult parameter for inexperienced observers to measure and he thought that instrumental observations would be more satisfactory. The definition of visibility objects was loose and led to disagreement between controllers and observers.

Mr. Lineham said that in marginal conditions the observer derived a great deal of comfort from the use of an instrument, especially when he realized that he might be called upon to give evidence in court later.

Asked to sum up by the Director-General, Mr. Hinkel said that it was necessary to know what the pilot really required, and to ensure that measurements of these quantities could be made either directly or indirectly. The discussion had emphasized differences between observers and instruments; these would have to be settled before any steps could be taken towards automation.

LETTER TO THE EDITOR

The estimation of maximum day temperature from the tephigram

The article in the September 1958 *Meteorological Magazine* on this subject by D. W. Johnston introduces a simplified practical technique for the estimation of the amounts of energy in the form of areas on the tephigram. The method of using the pressure difference between the top and bottom of the layer affected by heating and the equalizing of small areas instead of the actual measurement or estimation of relatively large areas on the tephigram is to be welcomed and has, as he says, the additional advantage of being independent of the scale of the tephigram in use. In practice the visual equalizing of small areas of differing shapes on the tephigram can be made with sufficient accuracy for all practical forecasting purposes.

In Figure 3 of Johnston's paper showing the areas to be used on occasions when convection cloud is expected to develop, the upper area considered includes an area between the saturated adiabatic GS, the dry adiabatic and the ascent curve. Since this additional area is provided by the latent heat released by condensation it should not, strictly speaking, be included in the two areas being equated to find the effect of surface heating and its inclusion has the effect of giving a lower forecast maximum temperature than would otherwise be the case. Johnston explains this as being due to the effect of the reduction of

the possible afternoon maximum temperature caused by a portion of the solar radiation being cut off by the cloud which develops. If these two are equal it is quite by chance. The actual amount of reduction will depend on the form of cloud which occurs. If, due to some stable layers at a higher level, the cumulus is caused to spread out on the top, the actual reduction will be much greater than on a day when the cumulus remains in isolated clumps or lanes with large areas of clear sky between.

The question may be rightly asked too as to what happens in the case of very unstable polar or arctic air in which convection can, at least theoretically, extend to the tropopause. In such a case the "latent heat" area between the saturated adiabatic of cloud ascent and the sounding can be sufficiently large to quite swamp the area to the right of the ascent curve at the bottom. In view of the fact that convection in such air masses is commonly of the type with well-marked clear periods between the clouds, the forecast maximum temperature evaluated from the tephigram is likely to be valueless.

It is suggested that a much sounder proceeding would be to use the dry adiabatic line FPS in Figure 3 extended to cut the sounding curve and to afterwards make an independent estimation of the effect of reduction by cloud. The magnitude of this reduction could in fact form the subject for a separate investigation.

Meteorological Office, Harrow. G. J. JEFFERSON

Reply by D. W. Johnston

I have read Mr. G. J. Jefferson's letter with interest and agree with him that the method outlined in my note for dealing with the case in which convection cloud develops is not correct. There will be, as he points out, a great diversity of results according to the depth of the unstable layer and to the existence or non-existence of a stable layer above. His suggestion of determining the maximum temperature, first ignoring the "latent heat" area and subsequently making an allowance for the effects of the development of convection cloud, is clearly sound.

REVIEWS

From earthquake, fire and flood. By R. Hewitt. 5½ in. × 8½ in., pp. 251, Allen and Unwin Ltd., London, 1957. Price: 18*s.* net.

In his preface to this book the author states: "I have tried both to present the human picture in the incidents I have recorded, and to give as simply as possible a detailed account of the causes and effects of the natural phenomena involved as far as they are known today". The publisher's note on the dust cover makes much the same claim in much less guarded terms. The result of the effort, in the opinion of the reviewer, is unfortunate; the two things do not mix well at all. Whilst "the scientific treatment of the physical agents of disaster", to use the terms of the publisher's note, does not measure up to the standards which a moderately trained scientist would expect, the attempt "to depict vividly the human story" leads to a profuse flow of almost journalistic prose which tends to swamp what science there is.

This is not to say that the book is wholly bad, or that the style exhibits the wilder forms of journalism—in which, for instance, "the worst storm in living memory" apparently occurs, at most places in the British Isles and probably

elsewhere, about every other year. There is some good material and the writing though often scientifically naïve and completely uncritical, is not on the whole atrocious. What is probably the worst fault is a lack of orderly presentation which makes each chapter read like a purely random catalogue of the form of disaster offered. Under the heading of "Wind and rain" part of the catalogue follows the course: Ross and Cromarty 1694, Illinois 1913 and 1927, China 1911, 1851 and 1887, U.S.A. (Johnstown) 1889, Ohio 1937, Kansas 1951, Lynmouth 1952, Lincolnshire 1920, Inverness 1829, New York 1888. The haphazard nature of this track through space and time is explained in part, but only in part, by the sudden jumps, without sub-headings, from one subject to another, as when New York 1888 introduces the treatment of snowstorms following the earlier discussion of thunderstorms and rainstorms. The sequence of separate subjects within the chapters does not seem to have any natural or logical basis, and for each subject in itself it is difficult to detect anything but chaos.

There are irritating mistakes and inconsistencies. On page 176 of the chapter on wind and rain, discussing the events of 15 August 1952, it is said that "eighty people were killed or drowned, mostly in Lynmouth". This possibly implies a rather wide meaning of the word "drowned", since in the summary on page 190 at the end of the chapter, "Statistics of floods, 1951–1955", the entry is "Lynmouth, Britain, killed 31", in substantial agreement with authoritative reports of the loss of life resulting from the Exmoor floods. On page 146 of the chapter on tropical storms, it is suggested that "a fast ship—if warned in time" might "run to port ahead of the (tropical) storm". But on page 150: "prudent captains would have put to sea when the barometer began to fall so rapidly—as it was they were caught in harbour by the hurricane"; and on pages 156 and 157, describing a typhoon striking Hakodate in September 1954, "five ferries put out from harbour to prevent being dashed to pieces at their moorings".

There are also a number of curious passages, especially among those dealing with reports of disasters in previous centuries, which are quoted without any critical comment and one does not know how the author expects them to be taken. In the discussion of the Inverness flood of 1829 on pages 177 and 178 the following account is given without quotation marks or any reference to the source; "The rains which caused the flood were fantastic. It was not like a normal heavy deluge of large thunder drops, but rather like a thick mist of fine particles. It was so heavy, however, that the whole atmosphere seemed solid with moisture, and small animals and birds were actually beaten to death by the ferocity of the downpour". There is no mention of wind, and "the scientific treatment of the physical agents of disaster" does not extend to any hint as to how a mist of fine particles could form a ferocious downpour. Brooks and Glasspoole in "*British floods and droughts*"[1] discuss the same storm and their account includes the sentence: "The downpour came mainly with a north-east wind, and its force was such that it penetrated all doors and windows facing in that direction", though they do also say: "Large numbers of game were destroyed, and *it is said* that this was due not to hailstones or to large raindrops, but to the way in which the drops were crowded together, so that the rain seemed to fall almost like a mass of water".

Perhaps one should not mention it, but of the 53 items in the bibliography, 18 are references to various numbers of the *National Geographic Magazine* and

many of the remainder are geographical. Only two are meteorological, though over thirty per cent of the material of the book is predominantly meteorological. There are 29 photographs, most of them excellent, to which there is not a single direct reference in the text. This could have been a much better book.

A. BLEASDALE

REFERENCE

1. BROOKS, C. E. P. and GLASSPOOLE, J.; British floods and droughts. London, 1928.

Farming weather. By L. P. Smith. 8 in. × 5½ in., pp. x + 208, *illus.*, Thomas Nelson and Sons Ltd., Edinburgh 9, 1958. Price: 15*s*.

Mr. L. P. Smith in his *Farming weather* goes near to achieving the impossible by interpreting a highly technical science in a manner comprehensible to the layman. His book sets out in clear and simple language all the intricate factors influencing the weather with particular relation to plant growth.

Many years ago the reviewer's grandfather had an excellent if irascible farm tenant. This worthy, on rising one dark morning, tapped the barometer which read "fair". Encouraged by this forecast he opened the back door with the intention of telling his men to prepare for sowing, but was immediately greeted by a violent downpour of rain. Returning to the house he seized the barometer and stood it against the garden wall remarking as he did so "Go and see for yourself you ——". Taking down his gun from above the mantelpiece he then demolished the offending instrument with two well directed barrels. Let it be said in his defence that he had not had the advantage of reading Mr. Smith's chapter on "Self help".

Since those days the progress in the science of meteorology has led to increased confidence by the consumer of weather forecasts, and it would be of interest if one could accurately assess the number of farmers who make full use of the services now available. If the percentage is low it is not the fault of the meteorologist but rather that increasing mechanization allows the farmer greater flexibility in planning and conducting his day-to-day operations which are carried out at ever increasing speed. Thus in pre-mechanized days it might be a matter of hours before the horses were harnessed, hitched to the drill, the implement taken to an outlying field and work begun. Today with the versatile tractor and self-hitching implements the operation may take but a few minutes to prepare. No longer need the man inform his master that it is too wet to plough, the prudent farmer can rapidly ascertain for himself whether in fact the machine will travel.

Moisture and temperature have a much greater influence on plant growth than anything that the farmer can contribute either chemically or mechanically. In his chapter on "Soil temperature and soil moisture" the author teaches many valuable lessons which can be learnt from an intelligent interpretation of these factors. In dealing with pests and diseases the advantage to the farmer in receiving reliable meteorological information before embarking upon a programme of spraying or dusting is immense. Heavy rainfall can completely nullify the effort both in time and money, and this problem is very fully discussed.

The difficulties in achieving more rapid progress in long-range forecasting are dealt with and the reader is reminded, gently but firmly, that the purveyors

of seasonal forecasts have no official status. It is surprising to reflect that many serious and often successful agriculturists are still firm believers in St. Swithin and the phases of the moon as having an inevitable influence on the shape of the weather to come. Such persons will be grievously disillusioned by the last chapter, but cheered maybe to learn that some of the well known old sayings possess a modicum of reliability.

So bewildering are the vagaries of our climate that disaster would speedily overtake the farmer who sits by the fireside awaiting a fair weather forecast. Let it also be said that the farmer who neglects to listen to and to interpret the forecast with intelligence will likewise be a considerable loser. But before endeavouring to put his own interpretation on the language of the forecaster, he will be well advised to read this admirable book which goes far to make plain a science which has perhaps suffered overlong and somewhat unfairly from a veil of mystery.

N. V. STOPFORD-SACKVILLE

Meteorology of the Antarctic. Edited by Van Rooy. 13 in. × 8½ in., pp. iv + 164, Falkland Islands Dependencies Survey, Stanley, 1957. Price: 15*s*.

Though the Antarctic regions have been much in the news in the last few years they are largely unexplored and their climate only known or inferred in broad outline. *Meteorology of the Antarctic* is the work of the South African School (with one Australian collaborator) which has made a special study of the climate and weather of the southern oceans and the Antarctic continent.

Chapter 1, written by J. J. Taljaard, briefly describes the geography of the Antarctic continent and the characteristics of the surrounding oceans. It is an indispensable introduction to the rest of the Volume. Chapter 2 (R. J. Venter) lists all sources of meteorological data in chronological order with brief descriptions of the information available. This is a valuable piece of work. Chapter 3 (J. F. Nagel) discusses meteorological instrumentation and the difficulties of observation in polar regions.

The remaining chapters describe the various meteorological elements and the general weather systems of the region. Chapter 4 (W. L. Hofmeyr) sets out what is known of the average pressure distribution at sea level; monthly averages are tabulated for every land station and for 26 oceanic squares with details of period and number of observations. Charts of average sea-level pressure are given for January and July and many aspects of surface pressure are analysed. Chapter 5 (F. Loewe) discusses available observations of precipitation and evaporation, both of which are very difficult to measure in the Antarctic. Chapter 6 (E. Vowinckel) describes the climate of the Antarctic Ocean as shown by observations from ships; little is known apart from the summer season. Chapter 7 (A. F. Fabricius) sets out in detail the climatic features of eight sub-Antarctic islands. Chapter 8 (E. Vowinckel) describes the climate of the coast of Antarctica as shown by the observations from the few bases which have been set up there from time to time. Chapter 9 (F. Burdecki) discusses the climate of Graham Land and its surroundings for which region there are relatively good observations. Chapter 10 (W. L. Hofmeyr) describes what is known of the upper air over the Antarctic; annexes give monthly mean upper air temperatures and geopotentials for nine stations throughout the year and for thirteen oceanic squares for summer months; also upper wind summaries for a few stations. Average heights of the standard pressure surfaces 700, 500 and 300 millibars are

charted for January and for 500 millibars for July. The surface inversion of temperature is discussed, as is also the continuing fall of temperature with height in the stratosphere in winter. In the stratosphere temperatures are much lower over the Antarctic in winter than over the Arctic, and the horizontal temperature gradient is negative towards the pole over a wide band of latitude. It is likely that the zonal geostrophic wind continues to increase with height in the stratosphere at least as far south as 75°S. (see Annex A) and this is confirmed by recent observations from Williams Base and Halley Bay. The winter meridional wind profile in Figure 3 will probably require amendment in this respect. The stratospheric jet stream is also probably stronger than in the northern hemisphere.

Chapter 11 (W. Schmitt) deals with the synoptic meteorology of the Antarctic. A few statistics of anticyclones and depressions are given and some synoptic examples of special interest are described. Blocking anticyclones are comparatively rare in the southern hemisphere but otherwise synoptic developments are broadly similar in both hemispheres.

This book will remain a standard work for many years. It forms an authoritative background to the many observations now being obtained during the International Geophysical Year and its authors have made a very valuable contribution to the meteorology of the Antarctic. The book is well printed on good paper and the maps and diagrams are excellent.

J. K. BANNON

Weatherwise gardening. By S. A. Searle and L. P. Smith. $8\frac{1}{2} \times 5\frac{1}{2}$ in., pp. 246, *illus.*, Blandford Press Ltd., 16 West Central Street, London, W.C.1., 1958. Price: 21*s*.

In his foreword to this book, Mr. Hay points out that so far as he knows nothing like it has appeared before. To the best of the reviewer's knowledge this is correct. The book is outstanding for the vast number of authoritative facts and figures which it contains and Mr. Searle and Mr. Smith have without doubt put a new slant on the art of gardening which will set many tongues wagging. The facts are in most cases supported by records and figures and are not merely gardeners' tales passed on willy-nilly from one generation to another. Any book worth reading must inevitably have taken the author much time and trouble and the amount of work expended on this particular volume surely is a record for its size so far as horticultural literature is concerned. Both authors set forth their material in a most clear and interesting way, the only major doubt being whether a prospective purchaser would, from a casual glance, think the contents too technical. This would be a pity, because in spite of rather deep and, to some, slightly boring chapters such as that on "Sunshine" and "Shadow", there is much in the rest of the book which is of inestimable value to any gardener worth calling the name.

The book's first section wisely commences by dealing with frost, the hazard which all gardeners fear most, but which, albeit, the majority do not adequately understand. This and later chapters should leave the reader in no doubt as to what site constitutes a major frost risk and what does not, although, as is rightly pointed out, knowledge of local conditions must be the safest guide rather than any rule of thumb technique. The unravelling of the seasons and their paths of progress across the country is excellently set out and the sections on sunshine,

rainfall, winds and temperature are equally revealing. One slight criticism, however, could be made of the map of meteorological stations on page 34. Here one notices that the three places used to give an average for north Wales are all *coastal* stations which would tend to give a rosier picture than inhabitants of Bettws-y-Coed or Llanberis would be prepared to accept. That, at any rate, is how things strike a gardener, for the reviewer's profession is horticulture and not meteorology.

Part two of the book is of particular value for the taking and interpretation of weather records and forecasts, and the six plates depicting cloud formations, with notes on what they portend, show how much can be read from them if one knows how. Part three cunningly reverses the picture as seen in section one by discussing how the garden can affect the climate and is perhaps the most valuable part of the book. Even so, a mere gardener cannot refrain from remarking that true double digging should *not* bring the second spit to the surface.

The last section, "Plant response to environment", is a book in itself and would be of particular value to students, but space does not permit adequate comment on it. Like the rest of the book, however, it is full of facts and explanations that perhaps many of us have not heard of before. Both the authors and the publishers must be congratulated on a job of work extremely well done—even the dust-cover is attractive.

E. G. GILBERT

OBITUARY

Mr. Michael O'Connor.—It is with deep regret that we learn of the death on 3 March of Mr. M. O'Connor, Senior Assistant (Scientific), at the age of 60. He joined the Office in 1925 as a Grade III clerk. He served some twelve years at outstations, but the greater part of his service was spent in the Instruments and Forecasting Divisions at Headquarters. Since 1951 he served in the Forecasting Research Division at Dunstable. Mr. O'Connor served in the infantry during the First World War from 1916 to 1919. He is survived by a widow and one daughter to whom the sympathy of all who knew him is extended.

WEATHER OF JANUARY 1959

Northern Hemisphere

The most striking feature of the mean pressure chart for the month was the polar anticyclone which was about 12 millibars more intense than usual and had exceptionally strong ridges extending over Greenland and western North America. Pressure anomalies were positive in all parts of the Arctic and reached +23 millibars on the eastern coast of Greenland. There were two low pressure centres in the Atlantic—European sector, one being situated just north of Newfoundland and the other over the Baltic where mean pressure was 12 millibars below average. Pressures were actually below normal everywhere in Europe and between approximately 20°N. and 50°N. over the Atlantic. There were also two low pressure centres over the North Pacific, one south-west of the Aleutians and the other over the Kamchatka peninsula, each being associated with an area of negative pressure anomaly. The North Pacific high, like the Azores high, was weaker than usual while the Siberian high was a little more intense than usual.

An area in which mean temperatures were below normal extended over Britain, Scandinavia and the Arctic Ocean from east Greenland to Novaya Zemlya, and at some places anomalies reached −5°C. Elsewhere in Europe temperatures were generally slightly above average. Positive temperature anomalies of up to +7°C. over Russia west of the Urals were a consequence of an increased southerly component in the mean flow, as were similar anomalies in the extreme east of Asia, north of Kamchatka.

Long periods of south-easterly advection of maritime air brought unusual warmth to eastern Canada and the Canadian Arctic, anomalies reaching +9°C. in Baffin Island. Negative anomalies of similar magnitude occurred at the surface in north-west Canada where conditions were strongly anticyclonic throughout the month. In the United States of America it was generally slightly warmer than usual over and to the west of the Rockies but a little colder than usual elsewhere. Record low temperatures were reported from Kansas and Texas during the first week, and for much of the month shipping on Chesapeake Bay was severely impeded by ice said to be the thickest for many years.

Over much of Europe the rainfall distribution was irregular, although totals were above normal at most stations in Scandinavia and the Baltic region. There was less irregularity in the precipitation pattern over North America, but it had little obvious relation to the mean pressure pattern. Between the 20th and 22nd of the month exceptionally heavy rainfall and serious flooding, reported to be the worst since 1913, occurred in Ohio and Pennsylvania. At about the same time tornadoes struck areas of both Tennessee and Kentucky causing much damage.

WEATHER OF FEBRUARY 1959

Great Britain and Northern Ireland

Anticyclones dominated the weather throughout the entire month which was extremely dry. It was cold with foggy periods during the first half of the month but became unusually mild towards the end.

During the first few days an anticyclone was centred over the North Sea with pressure over the British Isles close to 1040 millibars, only about 10 millibars below the maximum ever recorded in this country during February. Winds were easterly over southern districts but light and variable over Scotland, and weather was mainly dry and sunny but rather cold. Fog, which had formed at the end of January in the Glasgow area, was dense or thick at times and persisted day and night almost without a break, until the early hours of the 4th. During this time temperature remained below freezing in the foggy areas and fell to 15°F. or below at Aberdeen on three successive nights.

On the 4th the anticyclone moved to Scandinavia and from the 7th to the 19th covered most of Europe. Winds became south-westerly in Scotland but light and rather variable in central and south-eastern England. There was fog here and there on the 4th and 5th and this became widespread on the 6th and dense in places. Subsequently fog persisted throughout the day in many areas, chiefly in the Midlands and south-east England and was particularly widespread from the 16th to 19th. Temperature was below average, even out of the foggy areas, and weather generally was dull and gloomy from the 5th to

17th; on only one of these thirteen days was there any sunshine recorded at Kew. It was mostly dry except in south-west England and parts of Scotland.

On the 20th an anticyclone was situated in our South-west Approaches, the European anticyclone having declined. A cold showery north-westerly airstream, associated with a deep depression over northern Scandinavia, swept across the British Isles. Only in northern districts, however, was there any appreciable fall in surface temperature and, with this, the accompanying showers in Scotland turned to snow. The following day milder air from the Atlantic brought cloudy weather with rain or drizzle to most districts and by the 22nd temperature was everywhere above average.

On the 23rd an anticyclone covered the English Channel and northern France and by the end of the month had moved to central Europe. South-westerly winds persisted during these last six days, light in the south-east but reaching gale force at times in the north-west, and weak troughs of low pressure brought occasional rain to some western and northern districts, but in the east and south-east it remained mostly dry. Weather was very mild everywhere and on the 27th and 28th temperatures reached the average for May.

Both temperature and sunshine were below average for the first two and a half weeks, but thereafter were above it. The last few days of the month were particularly mild; on the 28th temperature reached 65°F. at Northolt and 64°F. at Cardington, while Ross on Wye, with 61°F., had its highest February temperature since 1891. On the 28th also, Kew, with 9·6 hours of sunshine, had its sunniest February day since records began there in 1881. The month was outstanding for its lack of rain. In England and Wales, with only 14 per cent of its average rainfall, there has only been one drier February, that of 1891, since comparable records began in 1868. Some places in south-east England had no rain throughout the whole of the month.

The prolonged dry weather enabled the planting and sowing of spring cereals to proceed favourably and good progress was made with the back-log of work. Most of the early potatoes were planted and in some areas growers were hoping for an early crop. Spraying programmes were up to schedule and fruit buds in some areas were on the move.

WEATHER OF MARCH 1959

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean†	Percentage of average*	No. of days difference from average*	Percentage of average†
	°F.	°F.	°F.	%		%
England and Wales ...	66	19	+2·4	115	+3	82
Scotland	63	16	+2·3	89	−2	91
Northern Ireland ...	61	27	+2·5	123	+2	109

* 1916-1950 † 1921-1950

RAINFALL OF MARCH 1959

Great Britain and Northern Ireland

County	Station	In.	*Per cent of Av.	County	Station	In.	*Per cent of Av.
London	Camden Square ...	1·74	110	*Pemb.*	Maenclochog, Dolwen Br.	4·30	109
Kent	Dover	1·68	93	*Carm.*	Aberporth	3·70	135
,,	Edenbridge, Falconhurst	2·40	119	*Radnor*	Llandrindod Wells ...	3·45	133
Sussex	Compton, Compton Ho.	3·19	129	*Mont.*	Lake Vyrnwy	3·77	95
,,	Worthing, Beach Ho. Pk.	1·49	87	*Mer.*	Blaenau Festiniog ...	5·63	84
Hants	St. Catherine's L'thouse	2·04	113	,,	Aberdovey	2·82	105
,,	Southampton, East Pk.	3·33	159	*Carn.*	Llandudno	·77	41
,,	South Farnborough ...	2·49	146	*Angl.*	Llanerchymedd ...	1·65	66
Herts.	Harpenden, Rothamsted	2·45	146	*I. Man*	Douglas, Borough Cem.	3·03	104
Bucks.	Slough, Upton ...	2·26	142	*Wigtown*	Newtown Stewart ...	3·65	118
Oxford	Oxford, Radcliffe ...	3·40	204	*Dumf.*	Dumfries, Crichton R.I.	3·08	112
N'hants.	Wellingboro' Swanspool	2·75	177	,,	Eskdalemuir Obsy. ...	4·14	105
Essex	Southend W.W. ...	1·08	82	*Roxb.*	Crailing...	·78	46
Suffolk	Ipswich, Belstead Hall	1·44	99	*Peebles*	Stobo Castle	1·76	73
,,	Lowestoft Sec. School	·87	66	*Berwick*	Marchmont House ...	·76	36
,,	Bury St. Ed., Westley H.	2·00	124	*E. Loth.*	N. Berwick	·38	24
Norfolk	Sandringham Ho. Gdns.	1·45	92	*Midl'n.*	Edinburgh, Blackf'd H.	·39	24
Dorset	Creech Grange... ...	3·50	139	*Lanark*	Hamilton W.W., T'nhill	1·56	65
,,	Beaminster, East St. ...	4·44	166	*Ayr*	Prestwick	1·97	93
Devon	Teignmouth, Den Gdns.	4·44	177	,,	Glen Afton, Ayr. San ...	...	...
,,	Ilfracombe	4·13	169	*Renfrew*	Greenock, Prospect Hill	3·85	95
,,	Princetown	9·27	157	*Bute*	Rothesay, Ardencraig...	...	...
Cornwall	Bude	3·41	159	*Argyll*	Morven, Drimnin ...	5·49	152
,,	Penzance	3·94	124	,,	Ardrishaig, Canal Office	5·08	122
,,	St. Austell	6·20	177	,,	Inveraray Castle ...	5·12	92
,,	Scilly, St. Marys ...	3·20	127	,,	Islay, Eallabus ...	3·42	110
Somerset	Bath	3·07	152	,,	Tiree	3·44	132
,,	Taunton	3·10	159	*Kinross*	Loch Leven Sluice ...	1·64	73
Glos.	Cirencester	2·95	133	*Fife*	Leuchars Airfield ...	1·05	65
Salop	Church Stretton ...	2·60	111	*Perth*	Loch Dhu	6·68	125
,,	Shrewsbury, Monkmore	1·63	101	,,	Crieff, Strathearn Hyd.	2·73	108
Worcs.	Worcester, Red Hill ...	2·07	136	,,	Pitlochry, Fincastle	2·83	131
Warwick	Birmingham, Edgbaston	1·75	94	*Angus*	Montrose Hospital ...	1·25	76
Leics.	Thornton Reservoir ...	2·04	110	*Aberd.*	Braemar	1·93	87
Lincs.	Cranwell Airfield ...	1·77	142	,,	Dyce, Craibstone ...	1·52	75
,,	Skegness, Marine Gdns.	1·68	116	,,	New Deer School House	1·76	80
Notts.	Mansfield, Carr Bank...	1·60	91	*Moray*	Gordon Castle	·92	54
Derby	Buxton, Terrace Slopes	2·58	90	*Inverness*	Loch Ness, Garthbeg ...	1·51	61
Ches.	Bidston Observatory ...	1·15	70	,,	Fort William	6·23	122
,,	Manchester, Airport ...	1·43	81	,,	Skye, Duntulm... ...	3·26	101
Lancs.	Stonyhurst College ...	1·67	64	,,	Benbecula	3·39	135
,,	Squires Gate	1·71	91	R. & C.	Fearn, Geanies ...	2·27	183
Yorks.	Wakefield, Clarence Pk.	·99	58	,,	Inverbroom, Glackour...	2·43	59
,,	Hull, Pearson Park ...	1·55	104	,,	Loch Duich, Ratagan...	6·76	130
,,	Felixkirk, Mt. St. John...	1·14	66	,,	Achnashellach	5·47	98
,,	York Museum	·99	69	,,	Stornoway	2·01	88
,,	Scarborough	1·47	97	*Caith.*	Wick Airfield	1·67	92
,,	Middlesbrough... ...	·49	34	*Shetland*	Lerwick Observatory ...	1·61	52
,,	Baldersdale, Hury Res.	1·52	65	*Ferm.*	Belleek	2·81	101
Nor'l'd	Newcastle, Leazes Pk....	·56	34	*Armagh*	Armagh Observatory ...	2·34	119
,,	Bellingham, High Green	1·61	74	*Down*	Seaforde	4·43	163
,,	Lilburn Tower Gdns ...	·63	29	*Antrim*	Aldergrove Airfield ...	2·58	128
Cumb.	Geltsdale, ...	1·75	76	,,	Ballymena, Harryville...	2·50	94
,,	Keswick, Derwent Island	3·84	109	*L'derry*	Garvagh, Moneydig ...	3·06	116
,,	Ravenglass, The Grove	2·82	104	,,	Londonderry, Creggan	2·71	97
Mon.	A'gavenney, Plâs Derwen	4·18	138	*Tyrone*	Omagh, Edenfel ...	3·42	127
Glam.	Cardiff, Penylan ...	3·28	129				

* 1916–1950

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